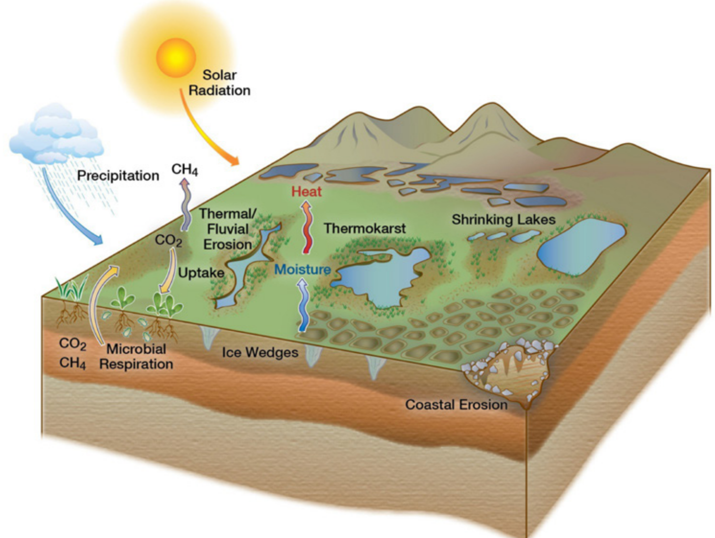
# Next-Generation Ecosystem Experiments–Arctic

ngee-arctic.ornl.gov

***Advancing predictive understanding of the structure and function of Arctic terrestrial ecosystems in response to climate change***

Characterized by vast amounts of carbon stored in permafrost, Arctic tundra is rapidly evolving as permafrost degrades in response to a changing climate. The mechanisms responsible for this system-wide reorganization have been unpredictable and difficult to isolate because they are initiated at very fine spatial scales, and because of the large number of interactions among the individual system components. To address this challenge, the Terrestrial Ecosystem Science (TES) program within the Department of Energy's (DOE) Office of Biological and Environmental Research (BER) is supporting a next-generation ecosystem experiments project in the Arctic (NGEE–Arctic).

***Overarching NGEE–Arctic science question: How does thawing of permafrost—and the associated changes in landscape evolution, hydrology, soil biogeochemical processes, and plant community succession—affect feedbacks to the climate system?***




**Landscapes in Transition.**
*A mechanistic understanding of what controls the rates, scales, and feedbacks of permafrost degradation is needed for system-scale prediction of permafrost dynamics in response to warming. NGEE–Arctic research activities are designed to identify and quantify the mechanisms underlying processes that control carbon and energy transfer in the Arctic biosphere, as well as how those processes play out in a changing Arctic landscape. [Lawrence Berkeley National Laboratory]*

The goal of the NGEE concept is to improve the representation of critical environmental processes in Earth system models (ESMs) by focusing on systems that are globally important, climatically sensitive, and understudied or inadequately represented in ESMs. In this approach, modeling and process research are closely and iteratively connected so that model structure and needs are considered in the development of process studies whose outcomes in turn are designed to directly inform, challenge, and improve models. Ultimately, the NGEE–Arctic project will develop a process-rich ecosystem model, extending from the bedrock to the top of the vegetative canopy, in which the evolution of Arctic ecosystems in a changing climate can be modeled at the scale of a high-resolution ESM grid. A similar TES initiative under way in the tropics (NGEE–Tropics) is examining how tropical forest ecosystems will respond to climate and atmospheric change.

## Integration Across Scales

Geomorphological features—including thaw lakes, drained thaw lake basins, and ice-rich polygonal ground—provide the organizing framework for integrating process studies and observations from the pore or core scale (micron to tens of centimeters) to plot (meters to tens of meters) and landscape (kilometers) scales. Within these discrete geomorphological units, mechanistic studies in the field and laboratory are targeting four critical and interrelated components—water, nitrogen, carbon, and energy dynamics—that determine whether the Arctic is, or in the future will become, a negative or positive feedback to anthropogenically forced climate change. Multiscale research activities organized around these components include hydrology and geomorphology, vegetation dynamics, biogeochemistry, and energy transfer processes.

**Patterned Arctic Landscape.** *Thousands of square miles in the Arctic are covered by networks of polygons that fill with water as snow melts early in the year. Slight variations in topography affect how water flows across the land surface and, in turn, how vegetation dynamics and carbon emissions respond to changes in soil water distribution. [Oak Ridge National Laboratory]*

**Hydrology and Geomorphology** research activities are focused on identifying and quantifying the coupled hydrogeomorphic processes being driven by permafrost thaw and degradation. The resulting variations in microtopography affect drainage networks, redistributing soil moisture at the local scale and across the landscape. This, in turn, drives changes in plant ecosystem processes and soil biogeochemistry that affect the amount and ratio of carbon dioxide ($CO_2$) and methane ($CH_4$) produced in the subsurface through microbial decomposition of soil carbon.

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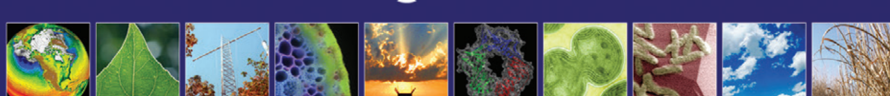

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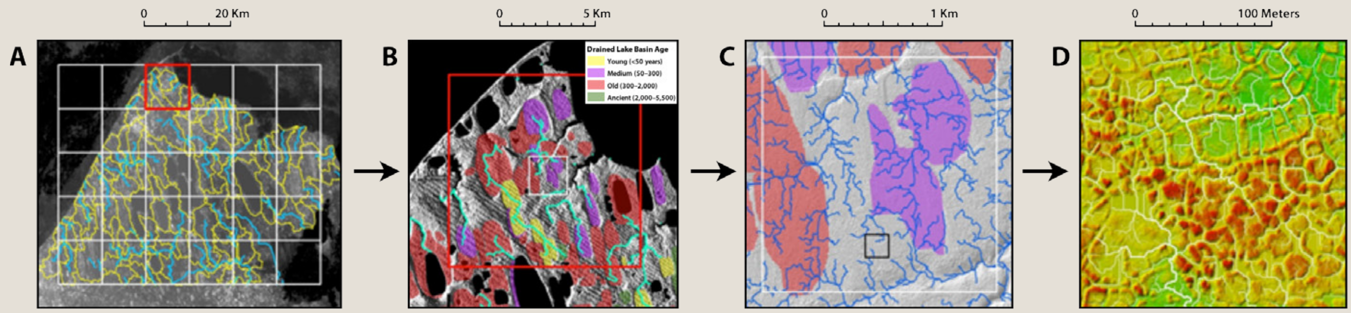
**Hydrologic and Geomorphic Features at Multiple Scales.** *At the scale of (A) a high-resolution ESM, (B) a single ESM grid cell, (C) a 2 × 2 km domain of high-resolution Light Detection and Ranging (LiDAR) topographic data, and (D) polygonal ground. Yellow outlines in panel A show geomorphologically stable hydrologic basins, connected by stream channels (blue). Colored regions in panels B and C show multiple drained thaw lake basins within a single 10 × 10 km grid cell (B) or a 2 × 2 km domain (C), with progressively more detailed representation of stream channels (blue). Colors in panel D represent higher (red) to lower (green) surface elevations for a fine-scale subregion, with very fine drainage features (white). [Los Alamos National Laboratory, University of Alaska Fairbanks, and University of Texas at El Paso]*




**Vegetation Dynamics** research activities aim to describe and quantify the mechanisms driving structural and functional responses of the tundra plant community to changing resource availability. A shift in the distribution of plant communities will drive important interactions between ecosystems, carbon cycle processes, and local to regional energy balance. Improved understanding of resource availability, particularly nitrogen and water, is needed to predict changes in plant community composition and expected feedbacks to atmospheric and climatic systems.

**Biogeochemistry** research activities are centered on the subsurface microbial, geochemical, and hydrologic processes that determine the fate of organic carbon. Increased temperatures will deepen the seasonal thaw layer, enabling the biological transformation of organic carbon buried in the permafrost to greenhouse gases that provide a positive feedback to warming. An improved understanding of carbon bioavailability in permafrost soils will greatly advance the modeling of greenhouse gas fluxes between subsurface environments and the atmosphere.

**Energy Transfer Processes** research aims to understand linkages among land-surface properties and processes that determine rate constants for energy transfers—albedo; heat capacity of surfaces (ice, soil, and water); and insulation provided by snow, vegetation, and surface water. Decreased albedo leads to warmer surfaces, promoting deeper thaw and permafrost degradation, in turn leading to a host of landscape changes. Climate, consequentially, helps to shape the surface energy balance of Arctic ecosystems through immediate effects of temperature and precipitation on snow cover and ice and long-term changes in vegetation processes, thermokarst, and soil moisture.

## Connecting Observations to Models

This comprehensive suite of NGEE–Arctic process studies and observations is being strongly linked to model development and application requirements for improving process representation, initializing multiscale model domains, calibrating models, and evaluating model predictions. A fundamental challenge for the NGEE–Arctic modeling activity is to relate new process knowledge gained at fine and intermediate spatial scales to states and fluxes relevant for integration in global-scale climate system models. Consequently, a nested hierarchy of models will be engaged at fine, intermediate, and climate scales, connecting process studies to models and models to each other in a quantitative upscaling and downscaling framework.

The overall objective is general knowledge and understanding through direct observation and fine-grained simulation of Arctic tundra ecosystems and the mechanisms that regulate their form and function. Specifically, this generalization will provide improved representation of Arctic tundra states and dynamics in the land model component of a coupled ESM.

## Leveraging NGEE–Arctic Investments

Led by Oak Ridge National Laboratory, the NGEE–Arctic project is a collaborative effort among scientists at Los Alamos National Laboratory, Brookhaven National Laboratory, Lawrence Berkeley National Laboratory, University of Alaska Fairbanks, and partners at universities and other state and federal agencies. In addition to TES, other BER programs involved in the NGEE–Arctic project include:

- Atmospheric Radiation Measurement Climate Research Facility
- Atmospheric System Research program
- Genomic Science program
- Climate and Earth System Modeling program

NGEE–Arctic also is affiliated with other federal and international monitoring projects.

All NGEE–Arctic data generated from observations, experiments, and models will be made available at **ngee-arctic.ornl.gov**. These data will include automated data collected from weather stations and trace-gas systems; observations from remote-sensing platforms; large campaign-based field work collections; and discrete datasets generated from chemical, biochemical, and molecular characterizations of soil, ice, water, and microbial or plant samples. BER provides research funding to leverage the NGEE investment through regular Funding Opportunity Announcements posted at **www.grants.gov**.

## Program Managers and Websites

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**NGEE–Arctic** (*ngee-arctic.ornl.gov*)

**NGEE–Tropics** (*esd1.lbl.gov/research/projects/ngee_tropics/*)

**Terrestrial Ecosystem Science** (*tes.science.energy.gov*)

**Climate and Environmental Sciences Division** (*science.energy.gov/ber/research/cesd/*)

**DOE Office of Biological and Environmental Research** (*science.energy.gov/ber/*)

**DOE Office of Science** (*science.energy.gov*)

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